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REPORT

ON

RAIL ROADS

AND

LOCOMOTIVE ENGINES,

ADDRESSED TO

THE CHAIRMAN OF THE COMMITTEE OF THE LIVERPOOL AND MANCHESTER PROJECTED RAIL-ROAD.

By CHARLES SYLVESTER,
CIVIL ENGINEER.

SECOND EDITION.

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1825.

Liverpool, December 15, 1824.

Sir,

HAVING been requested by a friend, a Member of your Committee, to inspect the Locomotive Engines and the Rail-roads near Newcastle and Sunderland, I have prepared the following Report, which he has desired me to publish and address to you. With my best wishes for the success of your most important and valuable undertaking,

I have the honour to be,

Sir,

Your most obedient Servant,

CHARLES SYLVESTER.

To Charles Lawrence, Esq.,

Chairman of the Liverpool and Manchester Rail-road Committee.

REPORT ON RAIL-WAYS.

Liverpool, 30*th November*, 1824.

IN every mechanical operation, whatever may be its nature, a certain effect or work has to be performed by some effort, called FORCE or POWER, which is intended to overcome other forces, or resistances, oppósed to the existing causes. If the whole of these causes are properly estimated before they are put into operátion, the result will be exactly foreseen; if, on the contrary, any of these causes, whether impelling or resisting, have not been properly estimated, the result will be different from that which has been foretold. This previous estimation of effects has been vaguely called *theory,* and there is a generally prevailing opinion, that theory and practice are oftentimes at variance; for we frequently hear such language as, "things being good in theory and bad in practice." Nothing can be more absurd. Every thing attempted to be practised has been the result of preconceived notions of the causes which would

interfere in favour of or against the result; but if the result be not what was expected, some of the causes have been wrongly estimated, or, perhaps, omitted altogether. Whichever of these may have been the case, we cannot call such a thing correct in theory, nor can any thing be correct in theory which does not hold good in practice.

Although, in this investigation, I have taken great pains to introduce all the circumstances for and against the accomplishment of rail-ways, I am well aware, that many have yet to be considered which must remain to be developed by experience.

We have long been acquainted with the effects and advantages of rail-ways in lessening the friction and the consequent saving of horse power. These have undergone various improvements in their means of lessening the friction. My object, in this report, is to explain the principles of moving wheel carriages along rail-ways, whatever may be the power employed. The force applied I consider as a certain pressure, which I call the moving force, and which I shall, in my calculations, express in pounds: the weight to be moved along the plane I shall also express in pounds.

With a view to make these principles better understood, I will propose an hypothetical plane, or rail-way, destitute of friction, to go quite round the earth, keeping every portion of the surface of the rail the same distance from its centre. These would be the precise data to constitute a level plane. It will be clear to all who are acquainted with central motion, that, if a carriage or other body be put in motion upon this hypothetical plane with

any given velocity, it will continue to revolve round the earth with the same velocity, supposing it to have no friction, nor to be otherwise resisted.

This hypothesis being admitted, I will now suppose, what we shall all readily allow, that this plane has a certain, but uniform, friction throughout, and that, in order to overcome this friction, we will suppose it to have some power travelling with it for that purpose. This being effected, it will, I think, be granted, that, whatever force we add to that which overcomes the friction, the carriage will be put in motion, and its velocity will increase, equally in equal times, as long as this extra force is continued. If, at any period of its motion, this extra force be withdrawn, leaving that still in action which balances the friction, the body will go on with the velocity it had acquired, and, if the path reached round the earth, it would continue to revolve for ever.

In order to apply this principle to practice, I have been anxious to get all the information I could on the subject of friction. For these valuable facts, I have been under much obligation to Mr. Stephenson, your engineer, and his friend, Mr. Wood, of the Killingworth Colliery.

They have ascertained, by experiment, that an empty coal waggon, which weighs 23.25 cwt., requires a force equal to about 14lbs. to keep it in motion, and they did not find, on varying the velocity, that this force was altered. When the waggons are loaded, the weight becomes 76.25 cwt., or 8,540lbs. If the axletrees of the waggon had been changed, according to the weight upon them, we should, doubtless, find that the friction would increase as the

weight; but in this case it is not so, and the friction of the loaded carriage, instead of being 53lbs., as the weight would give, is only 49lbs. In order to be rather over than under the truth, I have called it 50lbs. The engine is about eight tons, or 17,920lbs. I have stated the friction at about 100lbs.

In my examination of the locomotive engines at the Killingworth and Hetton Collieries, I have ascertained, that they are, in their present state, a great saving, compared with the employment of horse power; and that they are capable of so much improvement, as to put the matter beyond all doubt. My principal facts are taken from the Hetton Colliery. The engines and waggons, which I saw, traversed a plane, very little inclined, in the direction of the load: its length was 2,541 yards, or nearly 1½ miles: the rise in this length about 22.75 feet.

I made two journeys with the engine, which drew 16 waggons. In the first journey, we stopped for a short time on the way, but I found the average number of strokes per minute of the engine to be 45, which, multiplied by the circumference of the wheel, 9 feet, gives 405 feet per minute, or a little more than 4½ miles per hour. The second journey was performed in 15 minutes, which was at the rate of 5¾ miles per hour. The pressure of the steam in the boiler was said to be 50lbs. on an inch, and that upon the working piston 30lbs.; but, as there were no means of ascertaining this accurately, it must have been conjecture, particularly when the engine was going, for the safety-valve was then regulated by a spring, the force of which was very uncertain.

In order to put the principles, which I conceive to

belong to rail-ways, to the test, I have applied them to the facts which I obtained from this experiment, making the known data the means of finding what I did not get from observation, and comparing my results with the facts given by the estimation of the superintendent of the works. I have, therefore, taken one common speed for the engine, viz. 45 strokes per minute, which also limits the velocity to 5 miles an hour, or 7⅓ feet per second.

Agreeably to the principles laid down in the commencement, when a force is applied equal to the friction, the smallest force above that would, if continued, generate any required velocity. But it will be desirable to have such a force at command as will generate the necessary velocity in a short time, and, when that has been accomplished, to reduce this force, but still to leave it fully equal to the friction. If any part of the route has an inclination, there ought to be an extra force at command, above what would be required for a dead level. The plane, on which this experiment was made, inclined, in the direction of the load, about ⅓ of an inch to a yard. This is as great, and perhaps a greater, inclination than any rail-road ought to have, where loaded carriages go up and down. The moving force ought, therefore, to be always greater than the friction added to the force which is required to overcome the inclination of the plane. The latter force assists the body to go down, and equally resists it in moving upwards.

On this account I have used, or supposed, a moving force, which will give the velocity of 5 miles an hour, or 7⅓ feet per second, in the space of one minute.

This will be performed down the above plane by the engine making 45 strokes per minute, with a pressure of 9.7lbs. upon an inch, of each of the two cylinders, the area of each being 63.6 square inches. The weight of the engine and 16 waggons is equal to 154,560lbs., or nearly 70 tons. This velocity of 5 miles an hour being acquired at the end of one minute, the only force to keep the whole in motion, at the same rate, will be the difference between the gravity of the weight down the plane and the friction. The friction is 900lbs.; the gravitating force of the weight down the plane 540lbs.; therefore 900—540=360lbs.

If the same weight, at that speed, had to move on a dead level, and acquired the same velocity in one minute as before, the moving force would require to be 1,781lbs., which would require a pressure of 13.7lbs. upon 1 inch. But, after the speed is obtained, it will require only 7lbs. to keep it moving at the same rate. If the same load were required to move up the plane, it would require a moving force of 2,328lbs., or a pressure upon every square inch of 18.3lbs. And this velocity would be kept up by a constant pressure of 1,447lbs., which will be 11.3lbs. upon every inch of the piston.

In starting the engine, in the first instance, and giving the required velocity, it is probable the effects will agree very nearly with these calculations; namely, 154,560lbs., moved at the rate of five miles an hour with a pressure of 9.7lbs. upon every inch of the piston. Whether the pressure was reduced to the difference between the friction and the force upon the plane, which is calculated at 2.8lb., it is

difficult to say, as there was no steam-guage to indicate the pressure when the engine was going.

In observing the working of the engine, I should think the number of strokes should not be more than 45 or 50 in a minute. This limits the speed of these engines not to exceed five miles an hour, for the circumference of the wheels upon the rail being about nine feet, $45 \times 9 = 405$ feet per minute, or a little more than $4\frac{1}{2}$ miles an hour. Now, it would not be advisable to increase the number of strokes much beyond this rate, say 50. If, with this, it were required to go nine miles an hour, or 792 feet per minute, then $\frac{792}{50} = 15.8$ feet for the circumference of the engine wheel, which will be about 5 feet in diameter.

The weight I propose to be conveyed, by one engine, will be 38 tons, or 85,120lbs.; the friction of this, on a level plane, will be 494lbs. Then, the moving force to give this weight a velocity of nine miles an hour, in one minute will be 1,598lbs.; and, if we agree to have the same area, namely, 63.6, for each cylinder, the pressure upon an inch will be $\frac{1598}{127 \cdot 2} = 12.5$lbs.

In order, however, to give some idea of the power required for different loads, I have given a table, in which the engine is constructed about the size proper for conveying the above weight at the rate of nine miles an hour. I do not think it would be economical to make any engine much smaller than those used near Newcastle. The cylinders are nine inches in diameter, and the length of the stroke two feet. The boiler I would make about the same diameter, namely, four feet. I would make the fire-grate and

chimney of much greater area, and the wheels, instead of three feet, I would increase to five feet diameter.

In the principle laid down, the friction is supposed to be the same with any velocity which will be required. The resistance of the air, in the velocity of nine miles an hour, would be a little more than six ounces upon every square foot of surface exposed directly to the front of the moving body. This effect would vary with the direction and power of the wind; it will, however, be so little, that it may be safely neglected in this calculation.

Although the experiments made by Professor Vince, and by the French philosopher Coulomb, are sufficient to establish the law relative to the friction of bodies moving on planes, and that they also agree with the experiments by Messrs. Stephenson and Wood, at the Killingworth Colliery, it would, I think, still be desirable to repeat these experiments with greater velocities than have hitherto been tried. For this purpose, I would recommend a course of experiments upon a small scale, which would be of great value, and would save much expense in the construction of the real working machines. The scale on which I would make this experiment would be similar to that on which Mr. Smeaton made his experiments on water-wheels and wind-mills. This would consist of an upright revolving shaft, with an arm or moveable radius similar to that of a horse mill. The length of this I would make about 15 feet; the end of it would, therefore, move in a circle of 30 feet in diameter. At the extremity of this circle I would make a rail-way quite round the circle,

constructed in every respect in proportion to the present iron rail-ways, on the most modern plan. I would also have a carriage, or rather a series of carriages, having wheels suitable to the rails, and loaded in the same proportion. Round the upright central shaft I would coil a rope, which should go over a pulley, and have a weight to act at the end of the rope. This weight, by its gravity, would give motion to the revolving arm, which would be connected with the carriages to be drawn along the plane or circular rail-road. In forming the connexion between the arm and the carriages, I should place in the connecting chain or rope a spiral spring, similar to a spring steelyard. The carriages being loaded, and the moving force applied, it would in the first instance accelerate, as was stated in the beginning, the velocity, increasing with the time. I should have first observed, that a force or weight should have been first applied, which would just overcome the friction of the shaft and pulley, and then a weight added to give the carriages a certain velocity in a given time. When the body has acquired what may be deemed a sufficient velocity, the moving force may be diminished till the motion becomes uniform, which may be easily ascertained by a stop watch. During the time the velocity is increasing, the spiral spring must be carefully observed. Previous to making the experiment, this spiral instrument, which we may term a dynamometer, should be graduated into pounds and parts similar to a steelyard, by which means it will be known what force the friction is equal to in pounds, and whether, and how much, it increases whilst the velocity is increasing.

The weight used as a moving force in this apparatus, will have the same effect with the force of the steam on the piston of the engine, and may in every respect be compared with it, after making proper allowance for its own friction and the rigidity of the rope.

If these experiments should confirm this law relative to rail-ways, and even common roads, it may be turned to greater practical advantage than has as yet entered into the views of the present proprietors of rail-ways. We have hitherto only seen the force of animals applied to carriages, and the great weight conveyed by coaches in proportion to their speed has frequently been observed with surprise; this, however, would create much more wonder, if a force equal to the first power of the horse could be kept up for a length of time. This will be best explained by a statement of the decrease of a horse's power as the speed increases. If a horse, standing still, can by his strength keep a weight of 169lbs. from falling, when suspended over a pulley, he will exert 121lbs. when he goes 2 miles an hour, 100lbs. when he goes 3 miles an hour, 81lbs. with 4 miles an hour, 64lbs. with 5 miles, 49lbs. with 6 miles, 36lbs. with 7 miles, 25lbs. with 8 miles, 16lbs. with 9 miles, 9lbs. with 10 miles, 4lbs. with 11 miles, 1lb. with 12 miles, and at the speed of 13 miles he is not able to exert any power.

It will be evident, that if any power be applied, of the same energy as that of the horse in the first instance, and is not diminished by the increase of speed, the result will be very striking when compared with the effects of horses. The force of the engine is applied to the wheels to give them a rolling

motion, and on that motion depends the progressive speed, this power not being diminished by the speed, as is the case with the horse.

Having shown the advantages which may be derived from the application of moving force on rail-ways, I shall give a comparative view of these with canals.

The common roads differ from rail-ways only in their quantity of friction being about 7.5 times greater than the best rail-ways. When this friction is overcome by any power, supposing the road uniform, any additional force applied will uniformly increase the velocity of the carriage to any extent. The great irregularity of all common roads will not allow this fact to be verified, and we can only expect this law to be realized in rail-ways. With respect to canals, they are governed by a very different law from that of rail-ways. The resistance, instead of being constant, as in common roads or rail-ways, increases, at least, as the square of the velocity. Whatever power is required to move a floating body with any given velocity, it will require four times that power to give it twice that velocity, and nine times the same to give a treble velocity.

In order to give a more precise view of the relative advantages of rail-ways, common roads, and canals, I have arranged them in Table II. It appears from this table, that, at the rate of two miles an hour, the same moving force being applied to a canal and a rail-way, the canal has the advantage as two to one, but, at the rate of three miles an hour, the railway has the advantage over the canal as 22,400 to 19,911, and at the rate of 2.82 miles they are equal.

At the rate of nine miles an hour, for which the first table is constructed, the canal would only take a weight of 2,212lbs., which is less than $\frac{1}{10}$th of the weight conveyed on a rail-way, with the same power.

When a powerful horse commences his draught from a state of rest, he begins with exerting a force equal to 174lbs.; but his power to draw decreases with the speed, and, as the table shows, he exerts a power of 125lbs., at two miles an hour, by which he conveys 20 tons, including the vessel.

It will be evident, that the speed by means of horses, whatever may be the number, can never exceed 12 or 13 miles an hour, for at this speed they can exert no power. It will, therefore, be necessary, in order to travel at the rate of 9 to 10 miles an hour, to employ the power of steam, and this will be best performed by the locomotive engine. Although it would be practicable to go at any speed, limited by the means of creating steam, the size of the wheels and number of strokes in the engine, it would not be safe to go at a greater rate than 9 or 10 miles an hour. If the number of double strokes of the engine could be as great as 60 per minute, and the wheels on which it moved were the enormous size of 6 feet diameter, the speed would not be quite 13 miles an hour. If, by any chance, the wheels of the engine should get off the rails, which is sometimes the case, a greater speed than that above recommended would be attended with proportionate danger. It will appear, from the principles laid down, that any power greater than the friction being applied will cause the vehicle to gain equal velocities in equal times, as long as that excess

of power is continued. This may be shown from the theorems that are given at the conclusion. With a view to render the subject sufficiently intelligible to those who do not read algebraic formulæ, I shall give a short analysis of the principle in common numbers, which, for the sake of greater clearness, I will make even numbers. Suppose 40 tons have to be moved by an engine weighing 8 tons, which will leave 32 tons for loaded carriages. The friction of this weight will be about 500lbs. If a moving force equal to this be added, the body will be in a state to move with any additional force with the same effect as if it had no friction. Let this additional force be 500lbs. The whole weight being 40 tons, or 89,600lbs., the accelerating force will be to that of the force of gravity as 500 to 89,600, or $\frac{5}{896}$=about $\frac{1}{179}$th that of gravity. Now by gravity a heavy body falls through a space of $16\frac{1}{12}$ feet in a second, and at the end of that time it will have attained a velocity equal to double that space, or 32 feet per second. It is shown by writers on mechanics, that the velocity is doubled in 2 seconds, and trebled in 3, so that the velocity of a falling body may always be known by multiplying 32 by the time of its fall. But the force here stated is only $\frac{1}{179}$th that of gravity: hence, if the velocity of gravity be multiplied by $\frac{1}{179}$, or divided by 179, the quotient will be the velocity which the moving weight will have acquired in the same time. Suppose we wish the weight to acquire the velocity of 9 miles an hour, or 13.2 feet per second, and it is required to find the time in which the weight with the nett force of 500lbs. will arrive at the above velocity. This will be obtained by multiplying 179 by 13.2, and dividing

the product by 32. Thus, $\frac{179 \times 13.2}{32} = 74$ seconds, the time required. To give this in words, as a general proposition, multiply the whole weight to be moved by the required velocity in feet, and divide the product by 32 multiplied into the difference between the friction and the moving force. This will give the time required to gain the given velocity.

This rule applies only to a level plane. The force which an inclined plane gives to a weight will be obtained by multiplying the weight by the height of the plane, and dividing the product by the length. This force requires to be subtracted from the moving force like the friction, when the weight ascends, and added to it, when the weight descends.

Although a locomotive engine will move up a plane a little more than ⅛th of an inch* to a yard, it will be found, in practice, very desirable to have the line divided into dead levels and very short inclined planes, if there is any difference of level between the two places. The length of an inclined plane ought never to be such as will prevent a person from seeing the whole course of it from the top or bottom. As these planes would require to have fixed engines on their summits, it would be desirable to have as few as possible. An apparatus may be connected with these fixed engines, which will confine their office to the difference of weight between the goods going different ways. It will be evident, that the carriages going up these planes will require to be drawn by a rope or

* When the weight upon an inclined plane becomes greater than the friction, the wheels will turn, but no progress will be made. Agreeably to the data given for friction, the inclination at which this will take place is one-fifth of an inch to a yard.

chain, and it would be found, as is at present the case, that sometimes this rope breaks, and the carriages are precipitated and totally destroyed. Now such an accident as this with passengers would be fatal to the whole scheme.

Having given this subject some consideration, I shall propose a means which perfectly obviates this evil, and, what will still more recommend it, it will be seen by every person that there is no danger.

The carriages and the engine, by this plan, will require to be propelled up or let down the plane, the rope that comes from the fixed engine being at the bottom of the plane. The hook being in the rear of the whole and the rope under the carriages, I would now fix this hook to a separate carriage, which would be merely to propel them upwards. Between every pair of bearers of the rail, which are about a yard in length from each other, I would have pieces of cast iron quite across the road, of sufficient strength to resist the weight of all the carriages in the case of the rope breaking. The hook at the end of the rope should be fastened to one end of a bended lever of the propelling carriage. When the whole is in motion, the force of draught will act upon the bended lever, and raise another part of the same above the cross pieces of cast iron, and this will be kept in that position by the tension of the rope. If now the rope were to break, the end of the lever, which had been kept up, will fall, and instantly butt against the cast iron bar it last passed. Supposing the rope to break immediately before it passes a bar, the weight can never accelerate more than a yard, which would not give a considerable shock; at any rate, no danger could be experienced, nor would any thing but the rope be injured.

The propelling carriage here alluded to will have to go in the rear of the carriages up the plane, and in the front when they descend.

The fixed engines should be placed under the road, as much short of the commencement of the descent as will be equal to the space occupied by the line of all the carriages.

When the locomotive engine, about to descend, arrives at this station, the propelling carriage will have the hook of the fixed engine attached to it, and by its own power go on with the rope and propelling carriage. The locomotive engine will continue to work, till as many carriages are upon the inclined plane as will drag the rest forward. At this period the descending load will begin to raise a weight connected with the other end of the rope, which will just allow the weight on the plane to descend with a proper and uniform velocity. If the locomotive engine works all the time, a greater weight will be raised.

When the motion is the contrary way, and an engine with its load comes to the foot of the plane, the engine, in this direction, is supposed to propel its load, and the propelling carriage is now brought behind it. The hook of the rope from the fixed engine being attached, the whole goes up the plane, and the weight, which was raised by the descending load, now assists, or may be equal, to draw this load up the plane. The locomotive engine may keep working, if required.

The weights to be employed in raising the load, or being raised themselves by the descending load, may be so contrived as to admit of an exact adjustment to suit the different loads, whether ascending or descending.

By this means it will be clear, that the power required by the fixed engines will be the excess which the ascending load has above the descending, and this can in general be known, very nearly, before a rail-way is begun; so that the power of the fixed engine may be known beforehand. In a future work on this subject, I shall give a more detailed description of the reciprocating plan, with proper drawings for executing the work.

I hope by means of the tables, and the best description I have been able to give in this report, I have rendered the principles of rail-ways as clear, as our present experience will admit. I have avoided as much as possible every thing technical, and have not as yet used any algebraic formulæ. As, however, the theory of this important subject cannot be completely demonstrated and made general without these formulæ, for the sake of those skilled in the application of algebra to mechanics I shall subjoin the algebraic investigations, which have led to the deductions given in the former part of this report.

Each of the quantities, which will enter into this investigation, will be represented by appropriate letters. Let

W = The whole weight in pounds to be moved, including the carriages.

m = The force, also in pounds, applied to move the weight.

v = The velocity in feet per second with which W is to be moved when at its full speed.

t = The time required for the weight W to get the velocity v.

a = The area of the steam cylinders.

l = The length of the stroke.

n = The number of strokes per minute.

D=The diameter of the wheels of the engine which roll upon the rails.

F=The amount of friction of W in pounds, which is equal to the force that will keep it in motion with the velocity v.

H=The height of the plane, which, for the sake of simplicity, we will call 1.

L=The length of the plane, which, in all rail-ways, should never be less than 360 times the height.

p=The pressure upon a square inch of the piston, and ap=the whole pressure on both pistons.

f=3.1416, the circumference of a circle, the diameter of which is 1.

g=$16\frac{1}{12}$ feet, being the space a heavy body falls through by gravity, in one second.

Hence

Df=The circumference of the wheel.

Dfn=The number of feet per minute, and

$$\frac{Dfn}{60}=v.$$

Since the engine makes a double stroke for one revolution of the wheel, the speed of the piston to that of the carriage will be as $2\,l$ to Df; hence, the moving force will require to be greater in the ratio of $\frac{Df}{2\,l}$. If the crank of the engine turned the wheel upon a fixed centre, the mean effect of the same, as a lever, would be about $\frac{.6\,l}{2}$, .6 being the mean of all the sines in the quadrant. Since, however, the centre is moveable, and the fulcrum of the lever at the ground, it becomes similar to a pulley, in which the weight is to the power as 2 to 1. The power of this lever will, therefore, be doubled, and $\frac{l}{2}$ must be

added to $\frac{D}{2}$; hence we have $\frac{D+l}{2}.6 = (D+l) \cdot 3$. This, compounded with the quantity $\frac{2l}{Df}$ gives $\frac{(D+l).6l}{Df}$ for the multiplier of the moving force to give the velocity; but this has also to be multiplied by the velocity which gravity would give, in order to get the velocity of the moving weight. For the sake of getting the time in which this velocity is acquired, we will express the velocity which gravity would give in the time by 2 *gt*. Hence we have for the multiplier of the moving force $\frac{(D+l)\ .6 \times 2\,gtl}{Df} = \frac{(D+l)1\ .2\,gtl}{Df}$

Now *m* is stated to be the moving force to give the velocity *v* in the time *t*, if the body had no friction, and supposing it to move on a level plane, such as the hypothetical plane we imagined to go round the world. But I have also given a quantity for that, and must provide an additional moving force just equal to it. For the sake of simplicity, *F* may be used for that force. The true moving force, on a level plane, will be *m*—*F*, and the accelerating force $\frac{m-F.}{W}$ Now, 2 *gt* is the velocity which gravity would give to a heavy body in the time *t*; hence $v = \frac{m-F}{W} 2\,gt$. In the application of steam power the true value of *v* will be

$$\text{1st, } v = \left(\frac{m-F}{W}\right) \frac{(D+l)\ 1\ .2\ gtl,}{Df}$$

$$\frac{m-F}{W} = \frac{vDf}{(D+l)1\ .2\,gtl} \text{ or } m-F = \frac{WvDf}{(D+l)1\ .2\,gtl.}$$

$$2d,\quad m = \frac{WvDf}{1.2\,(D+l)\,gtl} + F$$

$$3d,\quad W = \frac{(1.2\,(D+l)\,gtl)\,(m-F)}{vDf}$$

In order to make these theorems universal, when the plane is, or is not level, we must use the quantity $\frac{HW}{L}$ with a plus or minus sign as the load ascends or descends. The theorem will then stand thus:

$$4th,\quad v = \left(\frac{m}{W} \mp \frac{H}{L} - \frac{F}{W}\right)\frac{(D+l)\,1{\cdot}2gtl}{Df}$$

$$5th,\quad m = \left(\frac{vDf}{(D+l)\,1{\cdot}2\,gtl} \pm \frac{H}{L}\right)W + F$$

$$6th,\quad W = \frac{m-F}{\frac{vDf}{(D+l)\,1{\cdot}2gtl} \pm \frac{H}{L}}$$

In order to find t, from theorem 4th, we have

$$\left((D+l)\,1{\cdot}2\;gtl\right)\left(\frac{m}{W} \mp \frac{H}{L} - \frac{F}{W}\right) = vDf$$

$$(D+l)\,1{\cdot}2\,gtl = \frac{vDf}{\frac{m}{W} \mp \frac{H}{L} - \frac{F}{W}}$$

$$7th,\quad t = \frac{vDf}{\left(\frac{m}{W} \mp \frac{H}{L} - \frac{F}{W}\right)(D+l)\,1{\cdot}2\;gl}$$

If the plane be level, then $H = o$, and in this case $\frac{H}{L}$ vanishes.

In beginning to calculate the size of the engine to convey a given weight W on a rail-way, the rate, or

speed, is the first thing to be fixed, which is v. Then the number of strokes per minute, or n, which should not exceed 50. Then find the diameter of the wheels, which will be got by the following reasoning: Since Df is equal to the circumference, nDf will be the space the engine passes over in 1 minute, therefore $\frac{nDf}{60}=v$, and consequently $D=\frac{60v}{nf}$. The length of the stroke should not exceed 2 feet. Since then n and l are constant, the only way in which different effects can be produced is in the alteration of a and p, and as it will never be advisable to let p much exceed 15lbs., this will also be limited, and a must be so taken as to accord with the above limitations. It will also be advisable not to allow D to be more than 5 or 6 feet.

In order to find the area of the cylinders, it will be remembered, that m, being the nett moving force under the piston, will be equal to the area into the pressure upon an inch, or ap. If this be substituted for m theorem 5th, we get

$$pa=m=\left(\frac{vDf}{(D+l)\,1{\cdot}2gtl}\pm\frac{H}{L}\right)W+F$$

$$a=\frac{m}{p}$$

$$p=\frac{m}{a}\text{*}$$

when $v=o$, $pa=F\pm\frac{WH}{L}$

and $p=\dfrac{F\mp\frac{WH}{L}}{a}$

* If p be in pounds on an inch, a will be in inches, and for two cylinders must be taken as equal to double the area of one piston.

When $H=o$, $p=\frac{F}{a}$, and if a force equal to $F\pm\frac{WH}{L}$ were to be in equilibrio with p, and act at the periphery of the wheel, when $v=o$,

$$p=*\left(F\pm\frac{HW}{L}\right)\frac{D}{.3(D+l)a}$$ When the engine moves uniformly with v, $p=\frac{F\pm\frac{HW}{L}}{a}$ the same as if at rest, and in equilibrio with the resisting forces, supposing the friction not to increase with the velocity.

Upon the whole, the advantages of a rail-road, on which the locomotive power is used, are so striking that it is matter of surprise this mode of conveyance has not been resorted to earlier. Its adoption, however, is now inevitable; and, when applied in proper places, and under judicious management, cannot fail of becoming highly beneficial to the proprietors and to the public. But nothing can be more delusive than to suppose, that because rail-roads are in principle better than canals, or high roads, they will answer everywhere; and yet the existing rage for them would seem to justify such an opinion. The pretensions held out by some of the projectors in various places, do appear to me unwarranted, either by facts or theory; and I have no doubt, but that when the public mind becomes more sober on the subject, the real importance of the rail-road system, great as it undoubtedly is, will be more correctly estimated.

* If the full effect of these levers were to be in operation at the same time, this denominator would be $\frac{D+l}{2}$ but since the cranks are at right angles to each other, the latter will require to be multiplied by .6, which will give $.3(D\times l)$.

This new application of locomotive power is of infinite importance to the country, and I should regret to see it abused.

P.S. Since commencing this report, these principles have been given in the newspaper called the *Scotsman*. The author speaks of it as a new idea, at least as it applies to rail-ways, although it is founded upon the facts given very long ago by Coulomb and Vince.

Whatever may be the claim to originality in this application, I have at least an equal claim with this author, as my introduction, which developes these principles, was read by several of my friends here, before the above articles were made public.

TABLE I.

1 Engine and Waggons.	2 Whole weight to be moved, in pounds.	3 Moving Force to give, in a minute, a rate of nine miles an hour, without friction, in pounds.	4 Force of the whole, on an inclined plane of 1-10th of an inch to a yard, in pounds.	5 Force to balance the friction, in pounds.	6 Moving force on a level, in pounds.	7 Moving force down the Plane, in pounds.	8 Moving force up the Plane, in pounds.
Engine .... Waggon ..	17,920 8,540	230.81 110	50 23.7	100 50	330.81 160	280.81 136.3	380.81 183.7
Together ..	26,460	340.81	73.7	150	490.81	417.11	564.51
With 2 waggons	35,000	450.81	97.4	200	650.81	553.41	748.21
3	43,540	560.81	121.1	250	810.81	689.71	931.21
4	52,080	670.81	144.8	300	970.81	826.01	1115.61
5	60,620	780.81	168.5	350	1130.81	962.31	1299.31
6	69,160	890.81	192.2	400	1290.81	1098.61	1483.01
7	77,700	1000.81	215.9	450	1450.81	1234.91	1666.71
8	86,240	1110.81	239.6	500	1610.81	1371.21	1850.41
9	94,780	1220.81	263.3	550	1770.81	1507.51	2034.11
10	103,320	1330.81	287	600	1930.81	1643.81	2217.81
11	111,860	1440.81	310.7	650	2090.81	1780.11	2401.51
12	120,400	1550.81	334.4	700	2250.81	1916.41	2585.21
13	128,940	1660.81	358.1	750	2410.81	2052.71	2768.91
14	137,480	1770.81	381.8	800	2570.81	2189.01	2952.61
15	146,020	1880.81	405.5	850	2730.81	2325.31	3136.31
16	154,560	1990.81	429.2	900	2890.81	2461.61	3320.01
17	163,100	2100.81	452.9	950	3050.81	2597.91	3503.71
18	171,640	2210.81	476.6	1000	3210.81	2734.21	3687.41
19	180,180	2320.81	500.3	1050	3370.81	2870.51	3871.11
20	188,720	2430.81	524	1100	3530.81	3006.81	4054.81
21	197,260	2540.81	547.7	1150	3690.81	3143.11	4238.51
22	205,800	2650.81	571.4	1200	3850.81	3279.41	4422.21
23	214,340	2760.81	595.1	1250	4010.81	3415.71	4605.91
24	222,880	2870.81	618.8	1300	4170.81	3552.01	4789.61

DESCRIPTION OF TABLE I.

Column

1 contains the engine and number of carriages.

2, the weights to be moved at the rate of 9 miles an hour.

3, the moving force to be applied, capable of giving that velocity, in addition to that force which just overcomes the friction. This is expressed by $\frac{vDfW}{(D+l)1.2gtl}$.

4, the force which the weight W would exert down a plane, the length of which, L, is equal to 360, when the height H is equal to 1 or $\frac{1}{10}$th of an inch to a yard. It is expressed by $\frac{HW}{L}$. This force would, of course, be nothing on a level plane.

5, the moving force in pounds equal to the friction, represented by F.

6, the moving force including that to overcome the friction, being the sum of column 3 and 5, or the force required on a level plane to generate a velocity of 9 miles an hour, by keeping the force in action one minute. When this velocity is attained, all the force in the 3d column may be withdrawn, leaving that in the 5th column which will be sufficient to keep up the velocity required.

7, the moving force required, when the weight goes down the plane, to give the required velocity in one minute. This will be found equal to the difference between columns 4 and 5 added to column 3. After this velocity is acquired, the last force may be withdrawn, leaving the difference between columns 4 and 5 to maintain the velocity required.

8, the force required to generate the above velocity in one minute, up the plane, being the sum of columns 3, 4, and 5. When the rate of 9 miles an hour is acquired, the force of column 3 is withdrawn, leaving the other two forces to keep up the speed.

VALUE OF THE LETTERS IN THE TABLE.

W=Weight of the engine=17,920lb., also of the carriages, each=8540lb.

F=Friction of the engine=100lb., also of the carriages, each =50lb.

v=Velocity at the rate of 9 miles per hour, or 13·2 feet per second.

D=Diameter of the engine wheel=5·03 feet.

l=Length of the stroke=2 feet.

t=Time, or 60 seconds.

f=Circumference of a circle whose diameter is 1=3·14 16; therefore Df, the circumference of the engine wheel= 15·8 feet.

H=Height of the plane=1 to

L=Its length 360.

g=Space which a body falls through in a second=$16\frac{1}{12}$ feet.

TABLE II.

VELOCITY.		WEIGHT MOVED.			Moving Force F to overcome Friction In Pounds.		In No. of Horses.		
1	2	3	4	5	6	7	8	9	10
In Miles per Hour.	In Feet per Second.	On a common Road. lb.	On a Rail-way. lb.	On a Canal. lb.	On a common Road and Railway for their weights.	On a Canal for its weight.	For a common Road or Railway	For a Canal.	Moving force to produce the velocity in one minute on the Common road and Railway, in Pounds.
2	2.93	3024	22400	44800	125	125	1	1	189
3	4.4	..	..	19911	..	281.25	1.2	2.7	221
4	5.86	..	..	11200	..	500	1.48	6	253
5	7.33	..	..	7168	..	781.25	1.87	11.7	285
6	8.8	..	..	4978	..	1125	2.42	21.8	317
7	10.26	..	..	3657	..	1531.25	3.27	40.1	349
8	11.73	..	..	2800	..	2000	4.66	74.5	381
9	13.2	..	..	2212	..	2531.25	7.21	144.9	413
10	14.66	..	..	1792	..	3125	12.36	309.1	445

EXPLANATION OF TABLE II.

Column.

1 is the velocity in miles per hour with which the load is to move.

2, the same in feet per second.

3, the weight to be moved on a common road supposed to be level.

4, the same on a level rail-way.

5, the weight which can be moved on a canal.

6, the moving force to move the respective weights on the common road and rail-way.

7, the moving force required to take its weight on a canal.

8, the same expressed in number of horses on a common road and rail-way.

9, the same for the canal.

10, the moving force required to give the velocity on the common road and rail-way in one minute. The same may be expressed in pounds upon an inch, by dividing these numbers by the area of the steam cylinder.

APPENDIX.

As I have in this report recommended the locomotive steam-engine, as the most economical power, for every part of a rail-way in which the rise is not more than $\frac{1}{10}$ inch to a yard*, and since this engine must be so far of the high pressure kind, as it is destitute of the means of condensing the steam by the air pump and cold water in a condenser, I have deemed it useful to give a comparative statement of the merits and demerits of the high and low pressure engines. This will not be with any idea of the latter ever being used on rail-ways, but to show how far the high pressure engine is dangerous, under what circumstances it has been so, and in what degree it differs from the low pressure engine in point of economy.

The low pressure engine works with steam of a pressure equal to 34 inches of mercury, or 17lbs. upon the inch, the effective power being 20 inches of mercury, or 10lbs. upon an inch of the piston. Of this 7lbs., about one is caused by the imperfection of the vacuum, which is generally 2 inches

* On examination of the plan and section of the intended rail-road between Liverpool and Manchester, I find the greatest rise, and that in only one instance, is not more than $\frac{1}{12}$ part of an inch; therefore, it is the most favourable which could well be constructed.

of mercury. The other six have to be divided between the friction of the steam piston and that of the air pump. The area of the latter to that of the former is about 6 to 1, and their diameters will be as 2·45 to 1, which is the ratio of their friction. Hence, if the 6lbs. has to be divided between the two, we get 1·74lbs. upon an inch for the friction of the air pump and 4·26 for the steam piston. Thus we allow for the low pressure engine 7lbs. to an inch for the loss of power and 4·26lbs. for the high pressure.

In the low pressure engine, we have, therefore, steam of 17lbs. acting against a pressure of 1, which is the value of the vacuum, and against 6lbs., the friction of the piston. In the high pressure engine, we have to act against 15lbs., the pressure of the atmosphere, and 4·26, the friction of the piston. Hence, in order to have a nett pressure of 10lbs. upon an inch, as in the low pressure engine, we shall require steam of a pressure equal to $15+4{\cdot}26+10=29{\cdot}26$; and if the steam, in both cases, is lost, their relative economy, in the consumption of fuel, will be in the ratio of their quantities of steam, or as 17 to 29·26, or 1 to 1·72.

As there will be a difference of about 20° of temperature, there will be a somewhat greater loss of heat by radiation in the high pressure engine. This, it must be observed, is the greatest difference, in point of economy, that can exist between a high and low pressure engine, since they are supposed of equal size and work with the same power.

If we were now to double the power of these engines, by doubling the area of the cylinder of the low pressure engine, and doubling the working pressure of the high pressure, the first will now be $2(1+10)+6\times\sqrt{2}=30{\cdot}46$, and the second will be $20+14+4{\cdot}26=38{\cdot}26$. The ratio is now as 1 to 1·26.

If the area of the low pressure were trebled, then the number for this ratio would be $3\times(1+10)+6\times\sqrt{3}=43{\cdot}4$, that for the high pressure $3\times10+14+4{\cdot}26.=48{\cdot}26$. Hence the

ratio in which the pressure of the steam upon the high pressure engine is 48·24, and on the inch will be 43·4 to 48·26, or as 1 to 1·11. The economy in the high pressure will still approach nearer to that of the low pressure by making the area of the latter 4 times, still keeping the pressure on an inch the same, and increasing the high pressure in the same proportion by increasing the pressure only, the cylinder and length of stroke remaining the same. In this case, the number will be for the low pressure $4(1+10)+6\times\sqrt{4}=56$, and for the high pressure $4\times10+15+4{\cdot}26=59{\cdot}26$, or as 1 to 1·058 nearly. In all these cases the temperature of the steam cylinder will be the same in the low pressure engine, not much exceeding 212°, the temperature of ordinary steam; that of the high pressure engine increasing with the pressure. In the first case, they are as 217° to 248°. In the second, the temperature of the high pressure cylinder will be 264°, that of low pressure remaining the same. In the third case, the temperature will be 280°, and in the fourth it will be a few degrees higher. This will cause an increased waste by radiation, but if the boiler and cylinder be cased, this loss may, in a great measure, be prevented; and in the last case, the high pressure engine comes very near the low pressure in point of economy.

In this comparison of the high pressure engine with the low Pressure, we have seen, that the economy increases with the pressure of the latter; but it must also be remembered, that the whole of the steam is consumed. This must necessarily be the case in the mode of condensing the steam in low pressure, but it need not be the case in that of the high pressure engine. Instead of discharging the steam into the open air, as is the common practice, it may be discharged into a large vessel, placed in the front of the engine, with a view to give it the best chance of being cooled by the surrounding air. This I should make of plate-iron, about 4lbs. to the square foot.

Its diameter might be three feet, and its height a little less than the smoke chimney, which would be about 15 or 16 feet. The capacity of this vessel would, therefore, be about 112 cubic feet, and its surface 144 feet. If, in throwing all the steam into this cavity, its temperature should be kept up to 180°, which, I think, would be the maximum in the warmest weather, the pressure in the interior would be equal to 7½lbs. upon an inch, supposing the vessel to be made perfectly air-tight, and provided at the top with a valve opening outwards, which would let steam or air out when the pressure was outward, and preserve the rarification, when the pressure was inward. This vessel would have to be made with great care, to be sufficiently air-tight. In the examples given, the high pressure steam has 15lbs. upon an inch of reaction. In the use of the condenser, in its perfect state, all the water would be returned to the boiler, with the exception of what escaped by accidental imperfection in the apparatus, and the strength of the steam employed would be reduced 7½lbs. upon an inch.

The comparison of the high pressure engine, under this improvement, with the low pressure, would be as follows: In the first case, when the engines are of the same size, we have, as before, for the low pressure $10+1+6=17$, and for the high pressure $10+7{\cdot}5+4{\cdot}26=21{\cdot}76$. If, as before, we double the area of the low pressure and the pressure of the other, we get $2(10+1)+6\times\sqrt{2}=30.46$ for the low, and $2+10+7{\cdot}5+4{\cdot}26=31.76$. We here see that with this additional vessel, when the pressure of the high pressure boiler is not more than 31·76lbs. upon the inch, the economy of the two is nearly equal, and very nearly all the water will be saved. To provide, however, for the little that may be lost, there may be that quantity put into the vessel when starting, and the bottom of this large vessel being connected with the small pump for supplying the boiler, the same will be mixed